GEM1506K
Heavenly Mathematics: Highlights of Cultural Astronomy
Project

Using The Heavens To Know Time
To
Using Time To Know The Heavens
- A Study of Calibrated Astronomical Devices

Group Number : 74

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Date: 11 October 2002

Preface

Time, whose discovery was mysterious, is an extremely intriguing entity that encompasses our lives. It is something that most people today take advantage of. Everyone knows how to read the time and knows exactly when to catch their favourite movie or to be on time for their flight at the airport. However not many people in today's world are concerned about how their watches and clocks began to tick or understood how the ancient human beings measured, told and read time without sophisticated technologies.

This project attempts to uncover briefly the history of time-telling, especially in the context of using astronomical information as a guiding hand. The natural movement of the Earth, the stars and planets have provided a repeating pattern with minute deviations which allowed time to be kept accurately. This project will also dwell on how the accuracy of time-keeping has improved over the years to what we are taking advantage of today. Lastly, we will explore the use and operation of calibrated astronomical clocks in the Middle Ages to read the positions of celestial bodies even without going out to look at the sky.

In this project, we try to restrict the discussion to the domain of astronomy as much as possible, without the interference of other disciplines of science.

Introduction

What is a clock?

From practical life experience, most people know what a clock is and what the function of it is. It is a device with which we use to tell the time. The Merriam-Webster dictionary provides a definition of a clock as 'a device other than a watch for indicating or measuring time commonly by means of hands moving on a dial' or broadly as 'any periodic system by which time is measured'.

To many in the present age, they would probably come in the form of a device with moving hands that is hung on the wall, or the watch on their waist and for some, the numbers ticking away at the corner of their computer screen. A calendar is basically a clock as well, except that it uses a time scale of days, months and years rather than hours and seconds.

What is the first clock then?

The first reliable clock available to all humans is definitely the sky. Although nature provides a certain amount of regularity in the form of seasons, cycles of life, migrations of animals and gives us a sense of passage of time, they are not universal, nor very accurate. The sky was the only source of accurate and undying repetition of patterns that literally ran like clockwork. As long as sky is not overcast and the observer has the knowledge, nothing stops him or her from using the sky to tell time from anywhere in the world.

Certainly, most of our ingrained concepts of time come from the sky; the day from the rising and setting of the sun, the month from the changing phases of the moon and the year from the positions in which the sun rises on the horizon and thus causing the seasons. Indeed many prehistoric societies uses the rising/setting position of sun as a marker to tell them when to perform a ritual or go on a pilgrimage or simply something that they had to do at that particular time of the year. It is not just restricted to the solstices; examples are given in a later section.

So powerful is the effect of the clock in the sky that humans have to undertake tremendous efforts to reconcile the fact that the year is not whole number of months or days and the month not a whole number of days. Weird and funky calendars rules all arise to try to correct the problem. Even in the present technological age, the sky still dictate the activities a large proportion of the human population. Like when to wake up to start work and when does a month actually starts in an observational calendar like the Islamic one. It is curious why in the age where industries, entertainment, warfare and numerous other human activities goes on round the clock but most humans are still bounded to the simple pattern of the rising and setting of the sun.

What is the first clock other than the sky?

Every living human being carries with them at least one biological clock. The exact mechanisms are still being studied but the effects are clear. For humans this clock is located in a small brain region known as the suprachiasmatic nucleus or SCN. It lies near the base if the brain at a point where the optic nerves cross as they enter the brain[1].

[1] The discovery of time, pg33

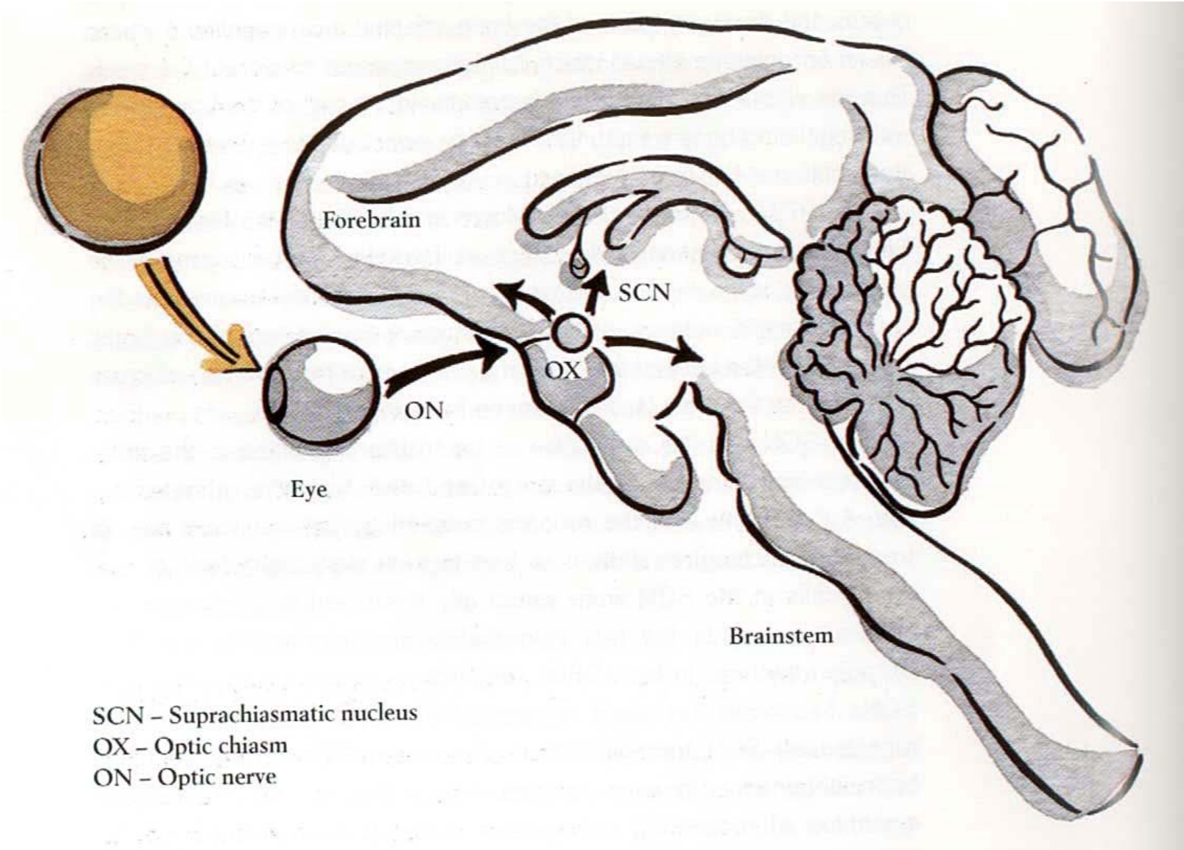

Figure 1

Research now points to two circadian clocks in our body, one that regulates the core body temperature and the other our sleep-wake cycle. The first run almost constant at approximately 24.2 to 24.3 hours[2] and thus certainly been set a long time back in evolution by the sun. The second clock which regulates the sleep-wake cycle is more interesting in that it drifts and resets much quickly than the first clock in reaction to light, i.e. sunrise and explains why the SCN is at the optic nerves. Famous experiments in which humans are kept away from the stimulus of the sun showed that this sleep-wake cycle can lengthen to 36 hours and thus their perception of time slowed down by 50 percent. For example, Italian Stefania Follini in 1989, stayed underground without any time cues for 130 days and she thought that only 80 days have passed. Furthermore, she exhibited up to 10 hours of continuous sleep and 26 hours of continuous waking.

For the rest of us who sees the sun everyday (almost), the second clock is constantly being reset to match that of the sun and try as we might, we may never decouple the day from the sun the way we decouple the month from the phases of the moon. These two clocks are “astronomical” in nature with the second one being actively kept in tune by the sun and thus can be counted as our first “astronomical clock”, a primitive way in which our body relies on the sun to help us tell the time to sleep and wake up.

[2] The discovery of time, pg30

A Brief History of How People used the Clock in the Sky

As humans begin to gain a mastery over their surroundings, they wanted to use the sky to tell more than just when to sleep and wake up. They wanted to know when will the next season come which is important to agriculture and how many sun rises have already passed. As civilisations and religions developed, they want to know the time to perform certain rituals and whether the signs in the sky signal a good time to have a wedding or festivals. Later on with the invention of the sundials we were able to divide the day into hours and order our lives in finer proportions. However the invention of mechanical clocks signalled the end of our dependence on the sky as a time teller. Other than the sun, most modern humans are hardly able to use any astronomical phenomena to tell time. The reverse has occurred, we now depend on our accurate clocks to tell how the sky will look like, which forms the theme of our project as we chart the progress of humans 'Using the Heavens to know time to using time to know the Heavens'

Time Keeping during Prehistoric times

For the prehistoric people, the sun worked well in telling them how long a day is and their main concern was what time of the year it is. This is because of seasons and the knowledge of the time of the year helped greatly in agriculture, which was the main activity then. As spiritual aspects of human activities began to flourish, it became important to determine when to perform certain rituals. They achieved that by observing the sky and made or used specific time markers.

Other than the sun, the moon is the next most prominent feature in the sky. The changing phases of the moon provided a convenient time marker, however they are not synchronized with the seasons and thus not very useful to agriculture. The use of the moon phases was mainly restricted to marking of the days that passed. For example, The Abri Blanchard bone shown in Figures 2a and 2b is a 30,000 year old eagle wing bone that may have craved lunar phases[3].

Figure 2a

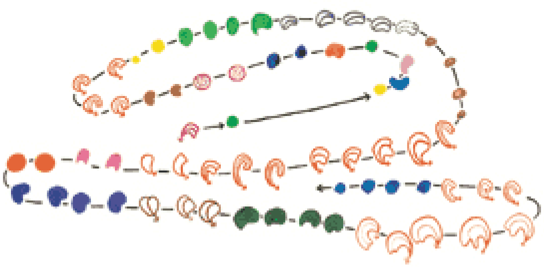

Figure 2b

[3] The discovery of time, pg43 and pictures from http://www.calacademy.org/calwild/sum99/watcher.htm

The rising and setting position of the sun was a much more useful time marker for prehistoric people. Many structures left behind indicate that they were constructed with the sun in mind. Numerous stone circles of the Neolithic Age ("new stone" age from 7,000 to 6,000 B.C.) in north-western Europe, the most famous being the Stonehenge shown on the right have stones that are well aligned to the solstices. They could have used by their builders to detect the solstices, other solar positions and even other celestial events to determine the time of the year. However there has much debate on whether the precise positioning of such structure is merely a coincidence. Figure 3a shows the position of the Stonehenge with relation to the alignments of the sun and the moon. Figure 3b is another picture showing the possible alignments of the Stonehenge with various celestial events[4].

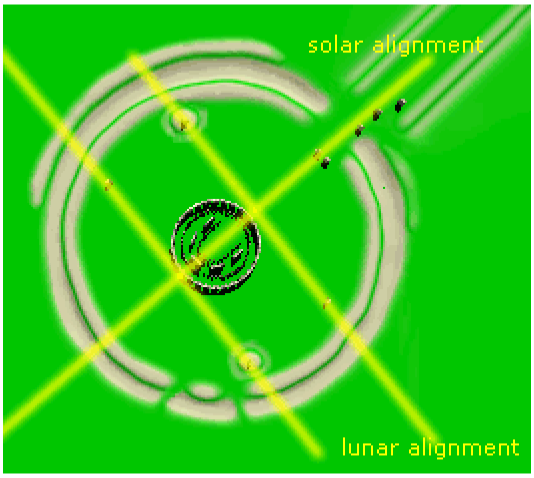

Figure 3a

Another type of monuments left behind by the Neolithic and Bronze Age (4,000 B.C.) that could have served as time markers was the 'cursus'. They are earthworks consisting of two parallel ditches and banks, generally tens of meters apart. One possible use for them is when the sun or moon shone directly down the cursus, it signalled the time for a ceremony and people to move along it. The longest cursus, the Dorset cursus runs for 6 miles and is aligned to the sunset of the December solstices[5].

By being prehistoric, monuments and artefacts are the only way we can gain an insight to how prehistoric humans could have used simple observational astronomy to help tell time. However by studying indigenous societies that are isolated from modern civilisation, we can gain further insights. The Hopi village of Walpi in Arizona uses the setting position of the sun against the peaks in Arizona to tell the time of the year[6], as shown in Figure 4. No doubt, many prehistoric people must have used their landscape as markers for telling time instead of using the special monuments.

4 Adapted from http://www.tivas.org.uk/stonehenge/stone_ast.html
5 The discovery of time, pg52
6 The discovery of time, pg108

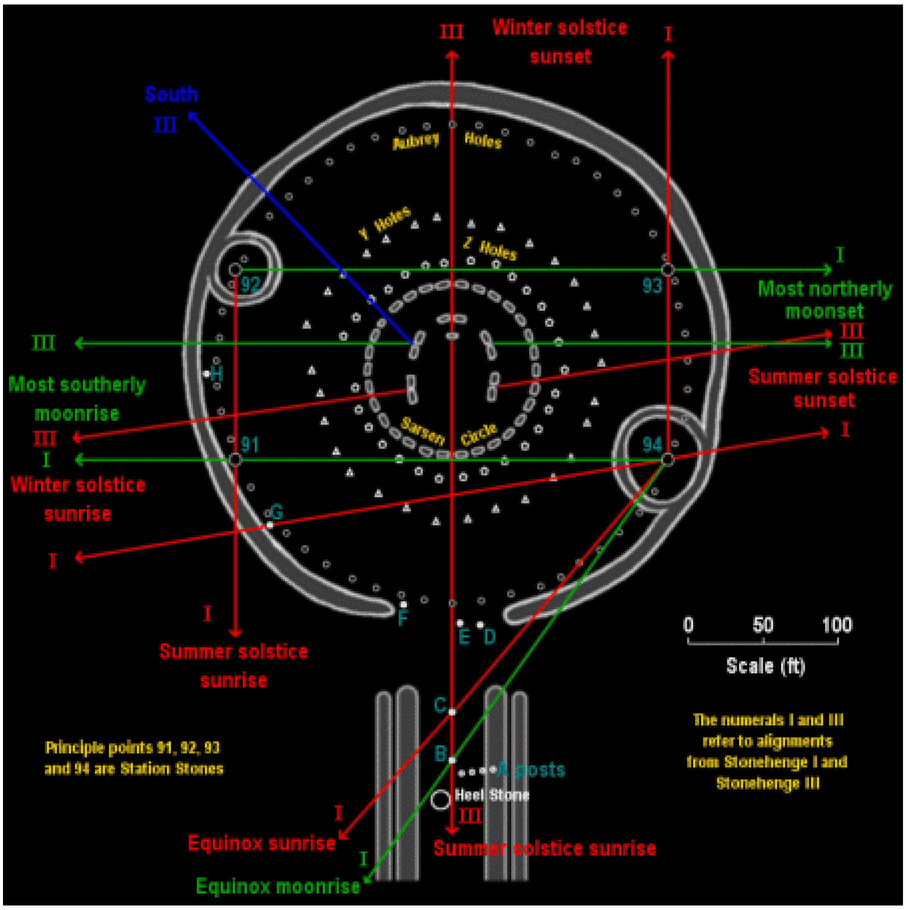

Figure 3b

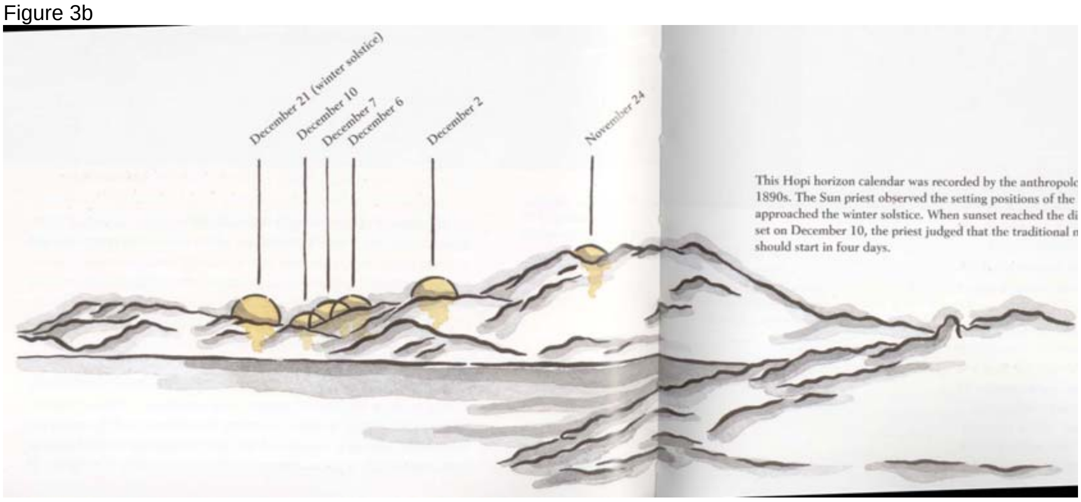

Figure 4

Time Keeping during Early Human Civilisation

During this period, the moon and the stars became the primary calendar and time telling tools. People spent a greater amount of time to study the repetition of patterns in the sky. With writing tools, people are better able to keep records and kept track of these patterns to develop calendars or basically long term clocks. Many calendars were developed using the phases of the month and exists today as the lunar or lunisolar calendars that many are still using. Without advanced mathematics and knowledge accumulated over time that we enjoy, these early calendar were almost certainly observational.

The other type of early calendar, were the star calendars and solar in nature. These calendars use the stars that are just visible before sunrise or after sunset to determine the time of the year. This form of time keeping is believed to have begun during the Babylonian period around 3,000 years ago persisted till the Middle Ages and remained till the present age as the common western astrological Zodiac.[7] They served more than just calendars, many a times as signs and warnings from the heavens.

These calendars have great use for agriculture as they were synchronised with the seasons. The Greeks developed their star calendars between 750 and 700 B.C.[8] and the poem, *The Works and Days*[9], written by Hesiod provided simple farmers a calendar to keep track of when they should carry out certain activities. He provides nine observations of the risings or settings of five stars or star groups as well as the winter and summer solstices. In most cases, he told the farmers what they should do on the occasion when the stars rose, set or culminated in the mid-sky. In three instances, he indicated the appropriate time for agricultural events by counting the number of days from a celestial event. For example,

> *Now, when Zeus has brought to completion sixty more winter days, after the sun has turned in his course, the star Arcturus, leaving behind the sacred stream of the ocean, first begins to rise and shine at the edges of the evening. After him, the treble-crying swallow, Pandion's daughter, comes into the sight of men when spring's just at the beginning. Be there before her. Prune your vines.*

Hesiod reminded the farmers to count 60 days after the winter solstices to watch out for Arcturus, part of constellation Boötes the Herdsman (See Figure 5) who drives the bears around. It is the fourth brightest star in our night sky and is found near the Great Dipper (Great Bear), furthermore it having orange tint made it easier to find. Incidentally, this giant star is only 37 light years away and also has a large apparent motion. In 100 years it moves across the sky a distance equal to about half the width of the little finger held at arm's length. In about a thousand years it will become too faint for the unaided eye and Hesiod's poem/calendar would have failed.

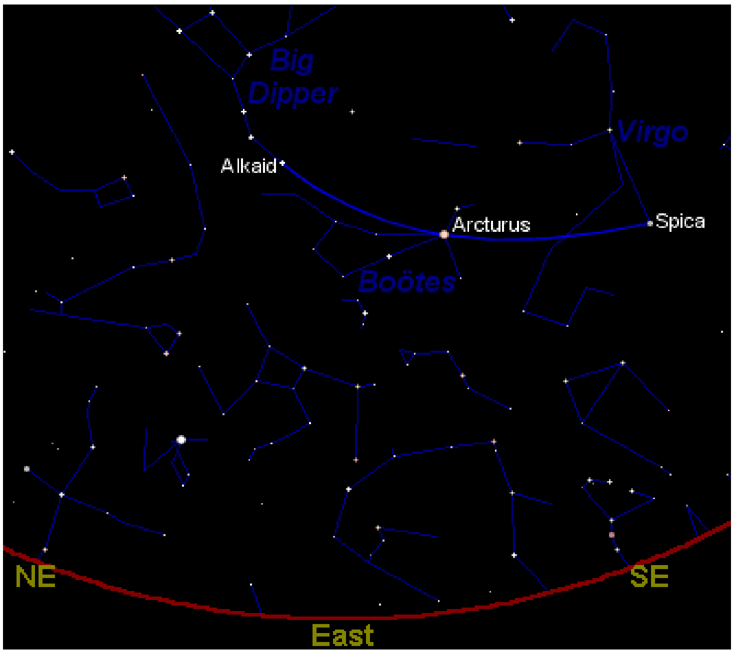

Figure 5

[7] The discovery of time, pg70
[8] The discovery of time, pg74
[9] An English translation of the whole poem can be found at http://www.sacred-texts.com/cla/hesiod/works.htm

Time Keeping during Middle Ages

It is during this period that sundials and mechanical clocks became common and many begin to divide their day into hours to better manage their days. Although the oldest sundials are Egyptian and date from about 1,500 B.C.[10], they were most common during this period up till eighteenth century. Other instruments used to tell time are astrolabes, quadrants, nocturnals and star clocks. There were other means like water clocks and burning candles/joss sticks. These were independent of astronomy but only kept time on a short time basis.

Astrolabe[11]

Basically to use it to tell time, the astrolabe (Figure 6) is suspended at or above eye level and the various movable parts are adjusted to align with the sun and other celestial bodies and the time can be read off. Conversely, if the time is known, the astrolabes can be set up to show how the sky should look like at the user's position instead.

Figure 6

Quadrant[12]

Quadrants are used to measure the altitude of the celestial body. A type of quadrant used to tell time is called Horary Quadrant from north India or Nepal. It is aimed at the sun and the suspended plumb line is used to read off the hour of day. Since at different time of the year, the sun is at different height, different scales are used accordingly.

[10] The discovery of time, pg122
[11] The Astrolabe; http://www.astrolabes.org/astrolab.htm
[12] Count On – Museum; http://www.mathsyear2000.org/museum/floor3/gallery9/gal2_2p4.html

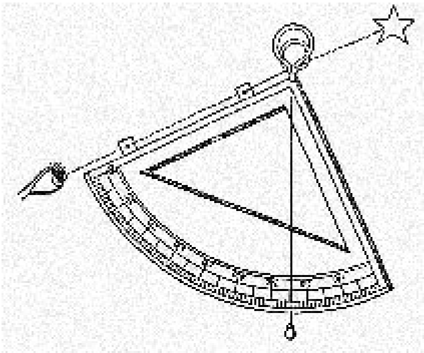

Figure 7a

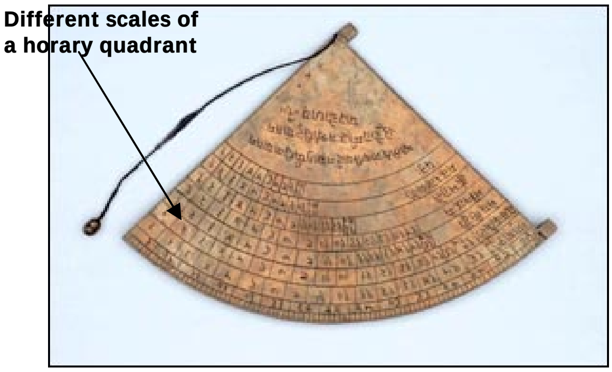

Figure 7b

Nocturnal and Star Clock[13]

Both use circumpolar stars to tell time. Figure 8 shows a star clock. The hole in the middle is aimed at the pole star and arm is moved to one of the prominent stars. The inner pointer is moved to point to the month and day; the inner circle is then read to tell the time.

Although it is probably not very useful in the southern hemisphere where the pole star is not visible. Even in a place like Singapore where the pole star is only one degree above the horizon, the star clock needs to be used with a compass to help find the north.

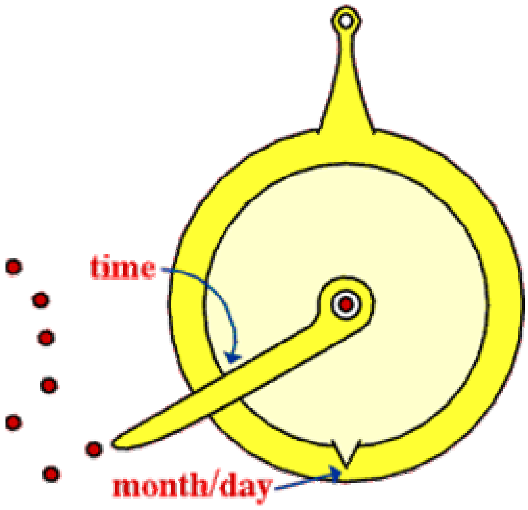

Figure 8

Sundials still remained as the most accurate and easy to use clock at that time. Even when mechanical clocks were invented, sundials were still used to adjust them as they were not very accurate and lost minutes or even hours a day. Furthermore sundials were made portable and later advanced sundial came with markings that allow a traveller to set his/her sundial for use in a particular city.

One thing to note is that earlier sundials usually used variable hours that divided days and night into 12 portions each without regard to the seasons and thus actual length of day and night. This was started by the Egyptians and it was only when mechanical clocks became common that hours of equal length that we are familiar today came into use.[14]

13 A simple DIY star clock can be found at http://www.lhs.berkeley.edu/StarClock/starclockprintout.html
14 The discovery of time, pg122, 164

This was also the age where man started to gain sufficient knowledge and skills to construct devices that relied increasingly little of the sky to tell time. Especially with mechanical devices like the early Su Song's astronomical clock and later clocks of increasing accuracy, humans were beginning to do the reverse, using time to predict how the sky will look like. Instruments like the astrolabe and Su Song's clock did just that. We will talk about Su Song's amazing astronomical clock the later section of this project.

Time Keeping in this Present Age[15]

Early escapement clocks of the Middle Ages can lost or gain up to an hour a day and have to be reset daily with sundials. Around 1670, the pendulum clocks based on the design of Christiaan Huygens brought the error of ordinary clock down to fifteen seconds a day. Man began to have the concept of minutes and seconds of time, which was not possible by any of the time telling devices or regular astronomical phenomena before and sundial were no longer used The quartz clock and watches that replaced the pendulum loses a second in months. However with caesium atomic clocks that lose only a second in ten thousand years, even Earth's rotation and thus the sky has become too inaccurate for our needs. This is because the Earth's rotation loses about one and a half milliseconds a century. In the future, an ion trap timekeeper would only lose a second in ten billion years.

We have reached the age which we are so confident of our time keeping devices that we no longer rely on astronomical observations to correct them. The sky as a clock serves no more for the modern human than it did for our ancestor before the prehistoric time described in previous sections. The rising and setting of the sun simply resets the internal biological clocks in the human brain present and the past. The heavens have changed from a clock to a piece of clockwork for us to study.

[15] The Discovery of Time, Chapter 8: The Triumph of the Clockmakers

The Astronomical Clock

In this section we shall deal with a mechanical device called the astronomical clock.

What is an Astronomical Clock?

We have established two different definitions for the astronomical clock from its two fundamental uses which seem to be on the opposite ends of the spectrum.

Firstly, it is a clock of superior construction, with a compensating pendulum, etc., to measure time with great accuracy, for use in astronomical observatories; -- called a regulator when used by watchmakers as a standard for regulating timepieces.

Secondly, it is a clock with mechanism for indicating certain astronomical phenomena, as the phases of the moon, position of the sun in the ecliptic, equation of time, etc.

Some background of the astronomical clock

As previously highlighted, there had been a shift from telling the time and the day from astronomical objects in the sky to reading from a clock. Mechanical clocks which indicated the position of heavenly bodies other than the sun were known as astronomical clocks. The first known mechanical astronomical clock had to be the clock by Su Sung in 1096AD[16]. However, the first known astronomical clock was likely to be from Greece even longer before than that, if the accounts of Roman author and architect, Vitruvius (88 – 26 BC) were accurate.

Su Sung's clock was destroyed shortly after it was made, and its creation was kept a secret in the first place, so sadly, its existence was little known in China. In the west, clock-making and astronomy were two different fields of science, and did not really overlap until the 14th Century, when there was a sudden improvement in the clock-making technology.

Development of the Astronomical Clock[17]

Here we shall refer to the astronomical clock as a mechanical clock because it is simply a mechanical clock whose calibration was based on astronomy. It should be noted that the operation of an astronomical clock is unlike the manual astronomical instruments presented in the previous section. Instead of requiring manual action when used, the astronomical clock is 'automated', in the sense that it is calibrated to run on its own without the need of manual intervention when users use it to take readings and measurements.

The earliest mechanical clocks in the world had no dials because its sole purpose was to strike its bell every hour. The oldest mechanical clock still surviving today is the one at the Salisbury Cathedral in the Great Britain. It was built in 1386.

The next 'generation' of mechanical clocks 24-hr clocks were the first of the mechanical clocks with a dial. However the dial was only used by the clock keepers to

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[16] Taiwan's Biggest Cuckoo Clock? - Recreating an Astronomical Timepiece; http://www.sinorama.com.tw/8506/506116e2.html#HowToWork

[17] Astronomical Clocks of the Middle Ages; http://www.almagest.co.uk/middle/astclk.htm

remind him how many times to strike the bell at every hour. As the reminder of the passage of time was conveyed to the public through the sound of the ringing of bells, the dials on such clocks were not for the public viewing. It was basically just a rotating plate, with a single pointer to indicate the time of the day. Figure 9 shows an illustration of a dial with 24 sections, one for each hour. There are only a few such clock still in existence today.

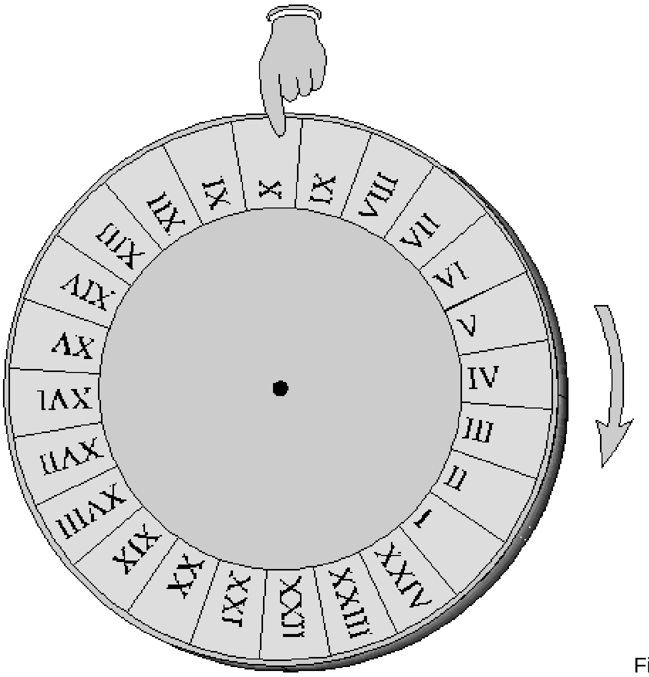

Figure 9

Next came the 'sun clock'. The main difference between the 'sun clock' and the 24-hour clock was that the dial of the sun clock was fixed and a sun emblem acting as the pointer was fixed onto a rotating plate. This fixed dial is also called the 'chapter ring'. Noon was considered the best time to start counting as a new day due to the fact that the time between one noon to the next is almost equal. Hence the sun emblem was calibrated to be at the top of the dial at noon.

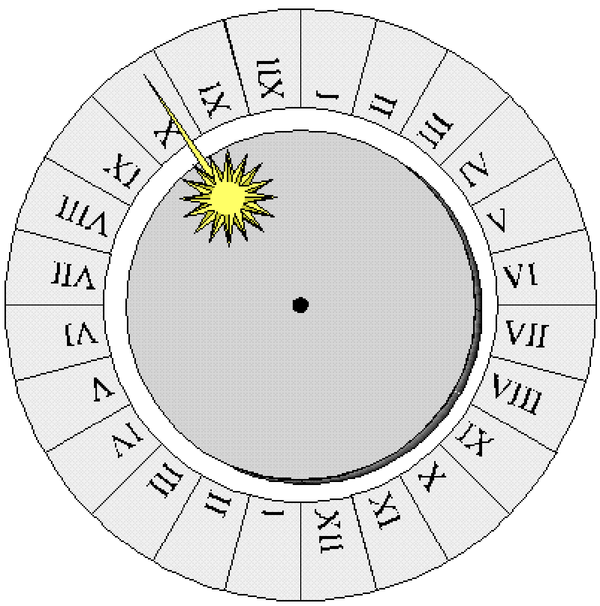

Figure 10

The first of a truly 'astronomical' clock in the second sense of the definition is a clock which shows both the sun and the moon, as shown in Figure 11. An additional moon plate, labelled 1 to 29, is added in the centre, which moves slightly slower than the outer plate. It makes one full revolution in 29½ days, which indicates the length of a lunar month. In addition to telling the time of the day, the clock can now also show the day of the month, through the indication of the sun pointer on the number on the inner plate which corresponds to the days of the month. The moon emblem in the centre plate indicates the new moon, thus when the sun pointer meets with the moon emblem, it is the start of a lunar month. The moon on the 'Sun-Moon Clock'represented by a half black, half white sphere which rotates during the course of a lunar month, indicating the phase of the moon

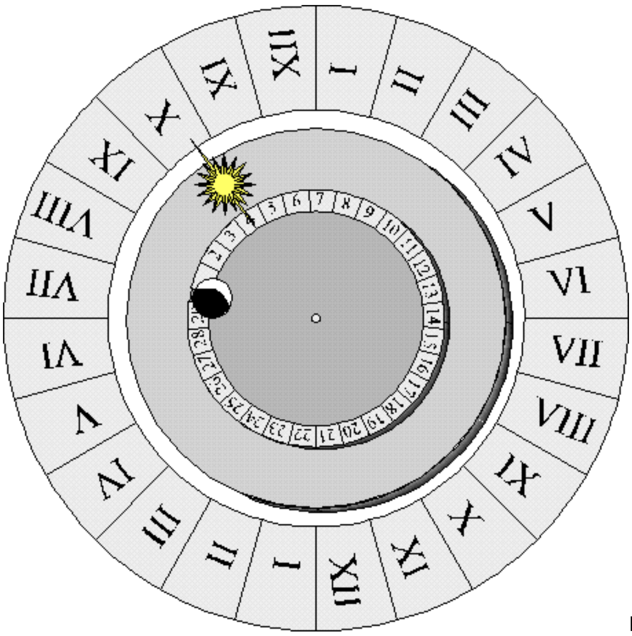

Figure 11

The development of the Sun-Moon clock led to the development of the Sun-Moon-Zodiac clock, as shown in Figure 12a. A third rotating plate with the zodiac signs (see Figure 12b) was added to the clock. This plate rotates at a rate faster than that of the sun plate, by about one degree per day. The reason for the zodiac plate to rotate faster than the sun plate is because the zodiacs are based on the sidereal day which is shorter than the solar day by a ratio of 365¼:366¼. Therefore the sun plate has rotated 365 times in a year, but the zodiac ring has gone rotated 366 times. The position of the sun pointer on the zodiac plate shows which constellation the sun overlaps at that point in the year. In the later stage of development, days and months added to the Zodiac dial and this enabled people to read the date as well as the astronomical position of the sun from the clock.

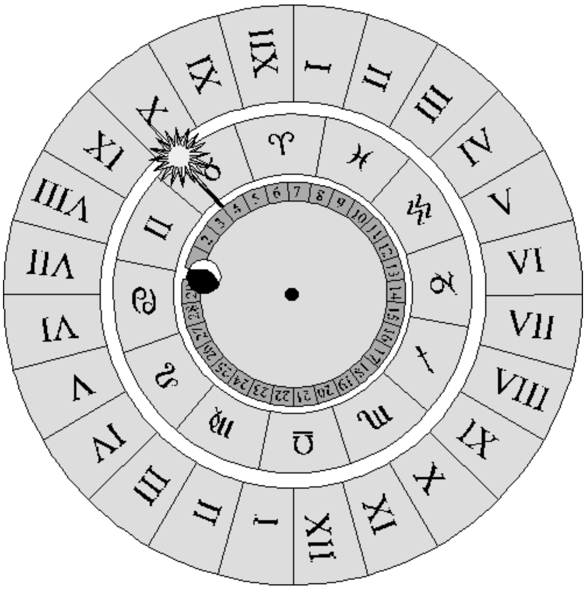

Figure 12a

♈	Aries	20 March - 19 April
♉	Taurus	20 April - 20 May
♊	Gemini	21 May - 20 June
♋	Cancer	21 June - 21 July
♌	Leo	22 July - 22 August
♍	Virgo	23 August - 22 September
♎	Libra	23 September - 22 October
♏	Scorpio	23 October - 21 November
♐	Sagittarius	22 November - 20 December
♑	Capricorn	21 December - 19 January
♒	Aquarius	20 January - 17 February
♓	Pisces	18 February - 19 March

Figure 12b

Development went one step further with the Sun-Moon-Zodiac-Ascendant, which was based on the astrolabe (See Figure 13a and 13b). The astrolabe was one of the common tools used in traditional astronomy to solve problems of time and space and the position of the Sun and the stars in the sky. It was ancient even at the time of invention of the mechanical clock-making, originating from Greece around 225BC. In fact, the first evidence of using an astrolabe in a machine was in the writing of a Roman author and architect, Vitruvius (88 – 26 BC). He described a clock made by Ctesibius in Alexandria[18]. He described a rotating field of stars behind a wire frame indicating the hours of the day. The clock described was probably a water clock, but the information is unconfirmed. If it really existed, then this was probably the first astronomical clock created, even before Su Song's clock.

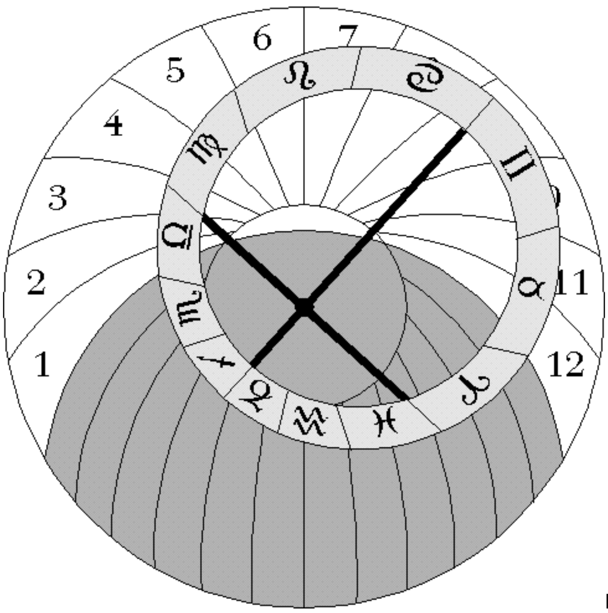

Figure 13a

[18] Astrolabe History; http://www.astrolabes.org/history.htm

The astronomical clock starts to become very complicated now. Instead of a zodiac plate, the zodiac signs are now placed on a ring (the 'rete'), the ring spins above a fixed plate or 'tympanum', on which the hour lines and the horizon (line between dark gray and white) is drawn. The 'rete' is pivoted at the centre of the 'tympanum', centre of pivot at the intersection of the two black lines. Like the zodiac plate in Fig 12a, the 'rete' rotates 366 times in one tropical year.

The 'rete' rotates at a constant rate. The zodiac is pivoted in such a special manner on the clock so that the summer signs (Gemini and Cancer) stay above the horizon (the white portion of the astrolabe in Figure 13a) much longer than the winter signs (Sagittarius and Capricorn) due to longer daylight in summer. This is also reflected on the 'rete'; Gemini and Cancer are further apart from one another, while Sagittarius and Capricorn are closer together. It is obvious from here that the instrument is biased to function accurately only in the Northern Hemisphere where it was invented.

The sun pointer is now a sun hand that stretches across the 'tympanum' onto the 'chapter ring'. The position of the sun in the sky can be determined by the point where the hand crosses the outer edge of the zodiac ring. It tells us not only where the sun is placed in the zodiac, but where the sun is placed relative to the terrestrial horizon.

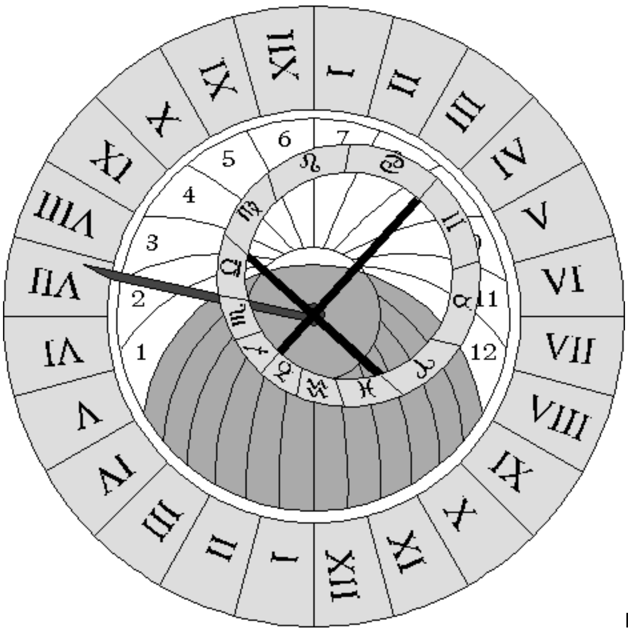

Figure 13b

The line between 6 and 7 of the 'tympanum' is the position of the meridian. At this point in the picture, the constellation Leo is at the meridian. Another pointer for the moon is sometimes added as well. Obviously, the position of the horizon was different from place to place. Thus, different 'tympanums' are sometimes provided for clocks, so that the clock could be used for different places on the earth.

Now the time in the day, the position of the sun in respect to the horizon and zodiac sign can be obtained from this clock. For example, in Figure 13b, the time is just before 8am, probably near the 21st of October.

Famous Astronomical Clocks

In this section of the project, we will give you a brief insight into a few of the most interesting astronomical clocks in the world. We shall explore 3 of them; namely the Prague Old Town Hall Astronomical Clock, Su Song's astronomical clock tower and the Strasbourg Cathedral Astronomical Clock.

Prague Old Town Hall Astronomical Clock

Figure 14

This technological and aesthetic marvel was originally constructed in 1410 by Mr. Mikulas of Kardan[19] and a Professor Sindel from the University of Prague. It was initially thought to have been built in 1490 by a man called Hanuš. In the past 600 years, there have been many renovations and repairs performed. In 1490, the clock was renovated and given a golden astronomical dial and Vladislav Gothic stone ornaments. In 1600s, more statues were added. From 1865-1870, repairs included a new calendar disc at the lower section of the clock (see Fig 1). During WWII, the clock was nearly totally destroyed. The clock was repaired to an almost new condition and at the same time, the clock was fixed to show 3 time zones: Central European Time, Old Czech Time and Babylonian Time. Note that the original clock had no moving figurines or statues initially. It only had relevant astronomical data.

The Prague Old Town Hall Clock has been able to keep accurate track of time for the past 6 centuries. The clock reflects that period of time based on the fact that the Sun on the clock's face rotates around the Earth and not vice versa.

Figure 15

[19] Astronomical Clock; http://user.intop.net/~jhollis/clock.htm

The clock consists of 3 different sections on Figure 15[20]:

1) The uppermost section
2) The middle section
3) The lower section

The uppermost section, added in 1865, contains the 12 Apostles. During the daylight hours, the 12 Apostles pass by two small windows every hour. The lowest section of the clock is the calendar dial, which was added in 1870. Created by famous Czech artist Joseph Manes, it consists of 12 medallions representing the months of the year and the 12 medallions of the zodiac. We shall focus mainly on the middle section.

The middle section is the oldest part, which is the astronomical dial and is, of course, the most essential part of the clock. This is the original section and remains exactly as it was in 1410. It shows the planets, sun, moon and stars moving around the earth. At the time it was built, the prevailing belief was that the heavens (Sun inclusive!) revolved around the earth. Nevertheless, it is extremely precise with this view, and the position of the stars, planets, and sun in relation to the earth and each other indicates the time of day and the day of the year.

The middle section displays 3 different sets of data:

1) The revolutions of the Sun
2) The revolutions of the Moon
3) The revolutions of the stars

The clock shows the Sun and the Moon moving through the different constellations. It is divided into red and blue halves representing day and night. The gold sun follows a circle through the blue part of the clock face during the day, dipping into the red bottom section at night (Figure 16). The time period that the people lived in is also reflected in the way the clock tells time. The numbers on the clock face are both Roman and Medieval Arabic (Figure 17). The clock day begins with sunset instead of midnight illustrating the Old Bohemian standards.

Figure 16

Figure 17

The clock movements are provided by large wheels mounted on the same axle. There are 3 gears in the clock that drives the clock to work. The first contains 365 teeth and drives the zodiac, the second contains 366 teeth and rotates the sun indicator and the last contains

[20] eTrav Pathways - Astronomical Clock; http://www.etrav.com/pathways/html/pragueclock.asp

379 teeth and drives the moon pointer. The clock also displays a half silvered half black ball that rotates and displays the different phases of the moon. The description of the mechanism of the Prague Astronomical Clock is very similar to that of the general astronomical clock discussed in the previous section and for similar reasons.

Su Song's Astronomical Clock Tower

Su Song was an imperial astronomer who designed the "False Sky Observatory" during the Song dynasty. Song also charted the stars for the emperor and perhaps led to the Chinese zodiac. One of Song's contributions to China was his astronomical clock (Figure 18). The astronomical clock was created by Su Song in December of 1088 to January of 1089. It was 30 feet (9 metres) high comprising of a celestial globe at the top synchronized with an armillary sphere placed just above it. It could, in addition to telling time, observe and demonstrate the astronomical phenomena.

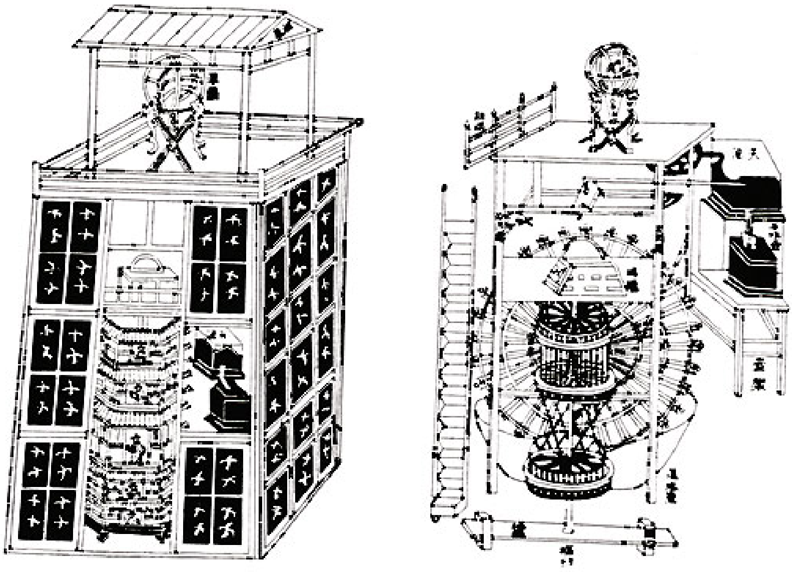

Figure 18

Xin Yi Xiang Fa Yao[21], written by Su Song in 1096, made a detailed description and exact figures of the Astronomical Clock Tower and this book is very valuable to study the instrument (Figure 19). Many scholars have studied the Astronomical Clock Tower, and completed a series of papers and books on it and constructed several models of this instrument since the 1950s[22].

[21] TU-Berlin China Study Group; http://station7.kgw.tu-berlin.de/english/abstracts/GaoX.html
[22] Sinorama Magazine - Recreating an Astronomical Timepiece; http://www.taiwaninfo.org/info/sinorama/8506/506116e3.html

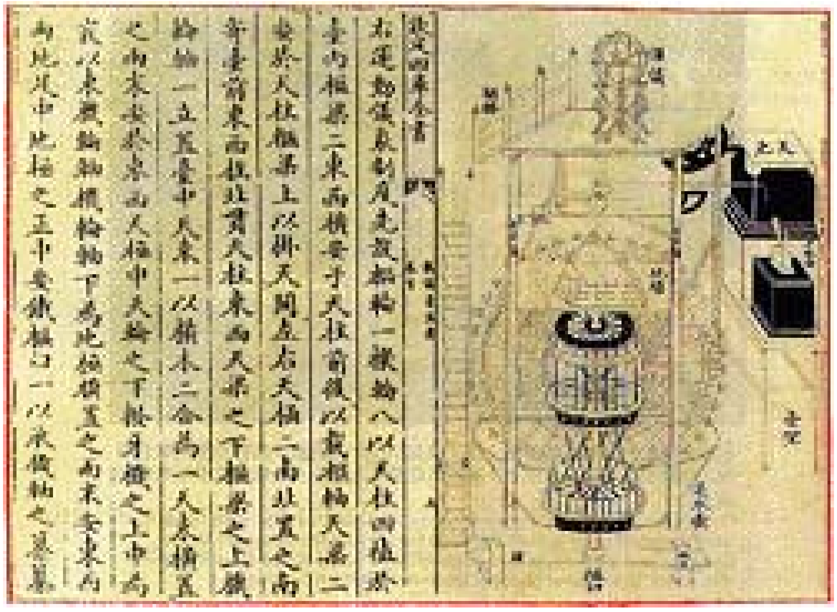
Figure 19

Su Song's water-powered clock tower was the world's first astronomical clock[23]. It had geared connections to an automatically rotating armillary sphere (circular metal bands set in motion to reproduce the great circles of the heavens such as the path of the Sun and the Moon)[24]. How was it possible for the whole apparatus with its armillary sphere, celestial globe and timekeeping system, to be driven by water?

At the heart of the clock, water poured at a constant rate into 36 tilting scoops attached to a large drive wheel (Figure 20[25]). The ticks of the clock were 24 seconds apart. Every 24 seconds, as the wheel remained stationary, a scoop would become just heavy enough with the water that was filing it to fall into a “down” position. This made the wheel rotate by one spoke and brought an empty cup into position under the water inflow.

The wheel had 36 spokes and so rotated every 14 minutes and 24 seconds for 100 times in a day: (14 x 60 + 24) x 100 = 86400 seconds

Compare this to how we measure time: a day has 24 hours with 60 min per hour with 60 seconds per minute: 24 x 60 x 60 = 86400 seconds

To save on the technical details, the water in the scoop turned the drive wheel, which in turn drove a train of gears to synchronously turn the observational armillary sphere on the top level of the tower, the demonstrational celestial globe on the middle level, and the timekeeping system inside the bottom level (Figure 21).

[23] Sinorama Magazine - How the Astronomical Clock Tower Worked: http://www.sinorama.com.tw/8506/506128e1.html
[24] The Discovery of Time, Chapter 8: The Triumph of the Clockmakers
[25] Tidsdokumentet, pressmaterial; http://www.tidsdokument.org/tidsdokument/press

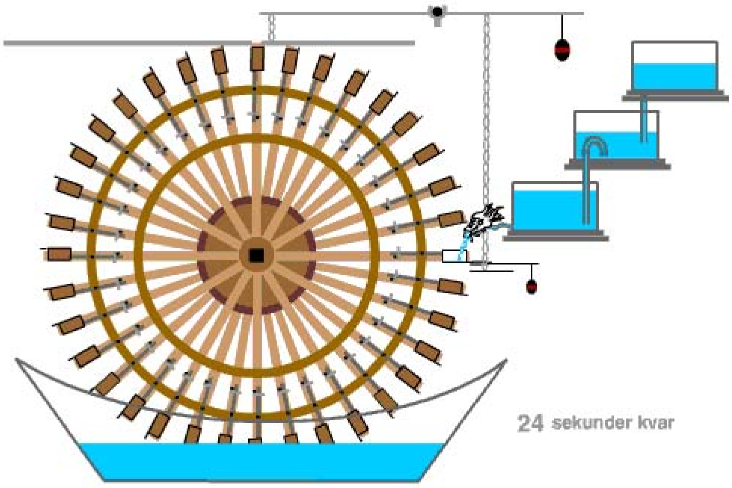

Figure 20

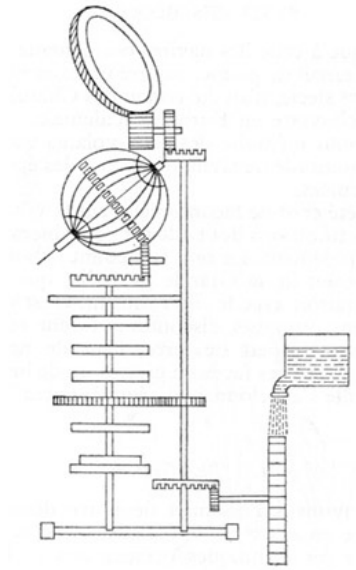

Figure 21

Strasbourg's Astronomical Clock

Figure 22

This astronomical clock is located in the Cathedral of Strasbourg otherwise known as Le Notre Dame. This clock is a mid-nineteenth-century version of the original fourteenth-century clock. The astronomical clock in the Strasbourg cathedral was already widely known in the fifteenth century[26]. The original was built in 1352-1354; it included a calendar dial,

[26] Die astronomische Uhr des Straßburger Münsters; http://www.gnt-verlag.de/programm/52/rez_sterne1994.shtml

pointers for the sun and moon, an astrolabe dial, and automated figures of the three wise men. Precisely how or by whom it was built is now only approximately known, since the clock was taken down sometime in the sixteenth century. Its even more intricate replacement, the clock that is seen in the cathedral today (although somewhat altered over the intervening centuries), was constructed in the 1570s. The name of the astronomer and mathematician Conrad Dasypodius (1531-1601) figures prominently as the designer, and he wrote up the contemporary description of it (Heron mechanicus [Strasbourg, 1580]).

Main sections of the Strasbourg Clock[27] (see Figure 22):
Bottom of clock: **The base** includes the black plinth, the case which holds the major cities dial, the astronomical clock, the cycles of the Sun and Moon and the solar time mechanisms.

Right side of clock: **The weight tower** with the rooster on top, houses the weights for the clock drives and allows them to fall about 3.5 metres unobstructed.

The central tower houses the main clock movement which has a double three-legged gravity arm escapement that not only provides the power to drive 8 of the clocks 13 mechanisms, but trips the others which have their own motive power.

This is one clock geared to time periods even longer than a millennium[28]. The clock stands inside the cathedral in a case of carved stone and wood 50 feet high and 24 feet wide. It is fully mechanical; everything is accomplished by wheels and gears, worms and ratchets, cams and followers, all driven by a pendulum.

The clock has a celestial globe in front that tracks the positions of 5,000 stars. As for time, the clock displays several versions: sidereal time, as measured by the earth's rotation with respect to fixed stars; local solar time, as measured by the position of the sun; and mean solar time, which averages out the seasonal variations in the earth's orbital velocity to make all days equal in length, exactly 24 hours. In addition, the clock also displays the current date, adding a day when required by leap year, and also displays the date of Easter, which is calculated using an arcane formula that can prove a challenge even for modern computers.

The accuracy of the Strasbourg clock is astounding, given that it must correct both for the seasonal changes in the length of the day and for changes in the earth's orbital velocity. If these corrections were carried out directly by the clock's mechanism, it would require the use of gears with some 80 million teeth. Instead, the clock approximates the corrections, but with sufficient accuracy that its error rate is less than a second a century. There are indications, however, that the clockmaker had periods of time even longer than a century in mind. The leap-year mechanism includes parts that move only once every 400 years; they came into play last year and will now lie dormant until the year 2400. There is also a gear deep in the works of the ecclesiastical calculator--the mechanism that determines Easter Sunday--that turns once every 2,500 years. And the celestial sphere out in front of the clock is geared to reflect shifts in the equinoxes of the earth's orbit that complete a full cycle once every 25,806 years. And this is a mechanical clock we are talking about which was built more than 150 years ago. Simply amazing, isn’t it?

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[27] Strasbourg clock model - Powerhouse Museum; http://www.phm.gov.au/exhibits/exib_perm/stras2.htm
[28] Galen Guengerich; http://www.allsoulsnyc.org/publications/sermons/ggsermons/keeping-time.html


Figure 23[29]

[29] Astronomical clock, Platform; http://www.cathedrale-strasbourg.asso.fr/english/astronomic1a.htm

The Modern Astronomical Clock

With today's technology and accessibility to computers, almost everyone can own an astronomical clock these days. One such example is the 'Planetarium' software for Palm operation system.

This software has the ability to:

- show where the constellations are whether they are below or above the horizon at any time (including the day)
- pick your location, for example, Singapore
- change the year, date and time of the sky view
- locate a certain object (defined as constellation, star, comet, planet) within an acceptable magnitude
- ability to give the coordinates of the object in terms of sight ascension/declination or azimuth/altitude

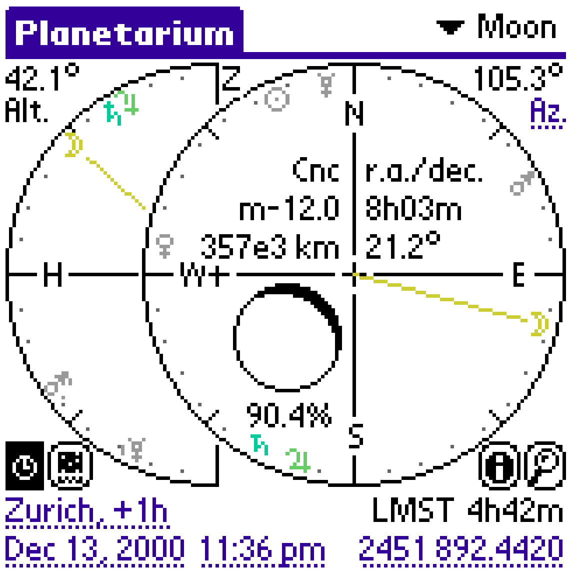

Figure 24

Given below is some of the information that can be read from Figure 24, a screenshot of 'Planetarium' software.

- The bottom left selects the location (Zurich) and automatically selects the time zone (+1h), the date (Dec 13, 2000) and time (11.36 pm).
- At the bottom right, the Local Mean Sidereal Time is given (LMST 4h42m) along with the Julian date (2451892.4420)
- In the main picture, the moon is the object in the sky that is selected.
- The values given on the top right are the altitude and azimuth of the moon (Altitude = 42.1 degrees, Azimuth = 105.3 degrees).
- The location in the sky is given by the 2 compass views.
- The right compass gives the azimuth (105.3 degrees and located just south of due east).
- The left compass gives the altitude.

- The bottom left of the right compass show a Moon which is 90.4% illuminated.
- The top left of the right compass indicate that the Moon is in the Zodiac of Cancer with a Magnitude of -12.0 and has a distance of 357e3 km from Earth.
- The top right of the right compass indicate the right ascension and declination of the Moon (8h03m, 21.2 degrees)
- The leftmost box on the bottom left gives one the ability to fix the sky at the current time.
- The 2nd from left box allows one to view the current sky view (whether it is day or night). The 2nd from right box gives information on a selected object such as magnitude, name and phase.
- The rightmost box on the bottom right allows the user to search for a certain object in the sky.

Indeed with this kind of technology available to us, it simplifies Astronomy to the masses as long as they know how to maximize the use of these devices.

Conclusion

In the project, we have presented the shift of how people tell time based on positions of astronomical objects in the sky to how people created devices to predict positions and movement of astronomical objects in the sky. The most impressive device presented here is undoubtedly the astronomical clock which was able to tell the time and the positions of celestial bodies. One should really ponder over the amount of hard work put into by people in the past in the construction of such instruments. They are massive projects, even to modern standards, where technology is available to assist in the calculation and construction.

We pay tribute to the philosophers, scientists and astronomers who have contributed to the development of the discovery of time. After working on this project, we have a totally different perspective of time whenever we look at our watches and clocks. Reading the time from our watches is simple, but the process of getting to what we have today actually took thousands of years.